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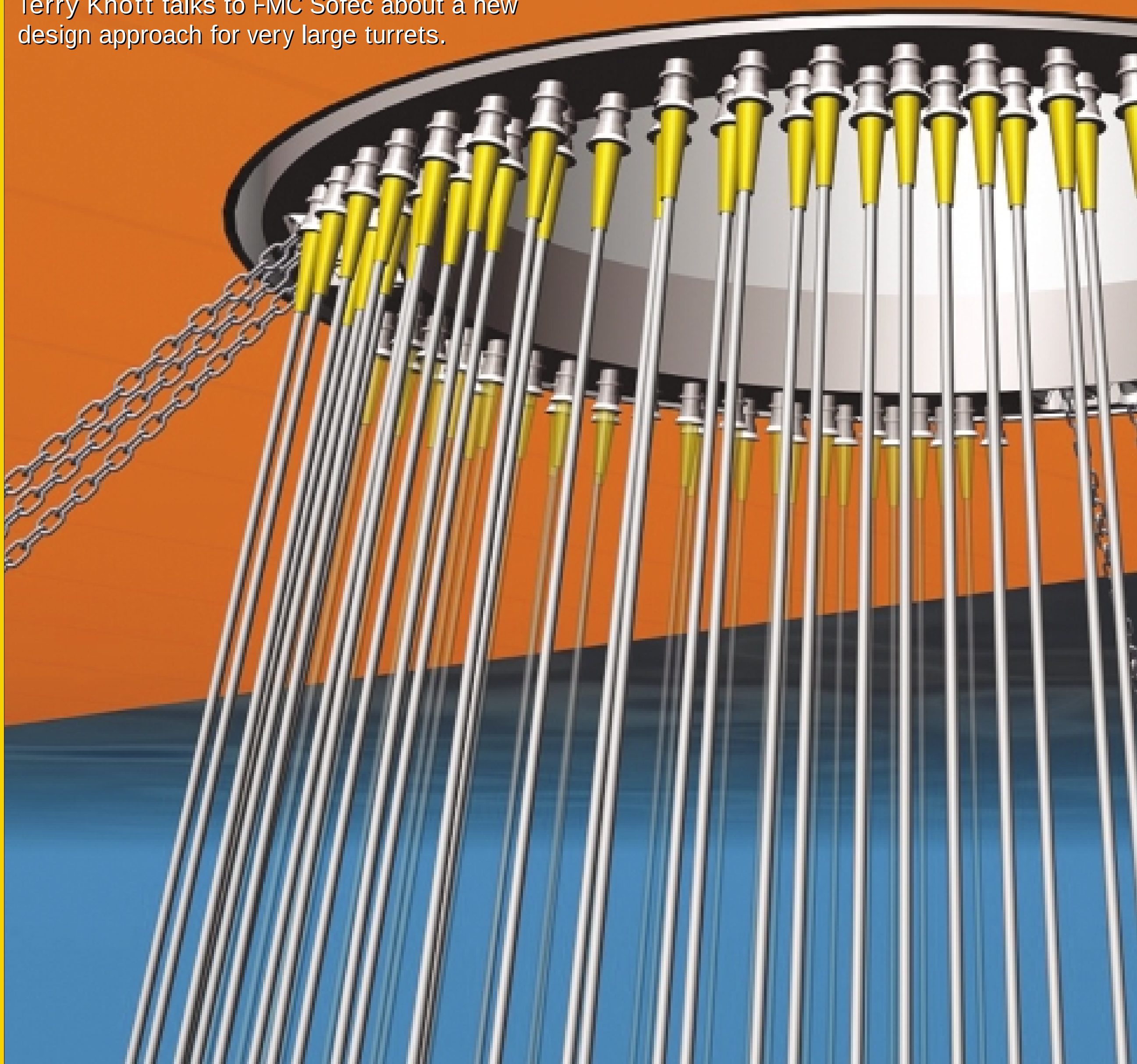
Big wheels keep on turning

Turret-moored FPSOs could soon see a hundred or more risers coming in through the moonpool, dispelling the idea they have reached their size limit.
Terry Knott talks to FMC Sofec about a new design approach for very large turrets.



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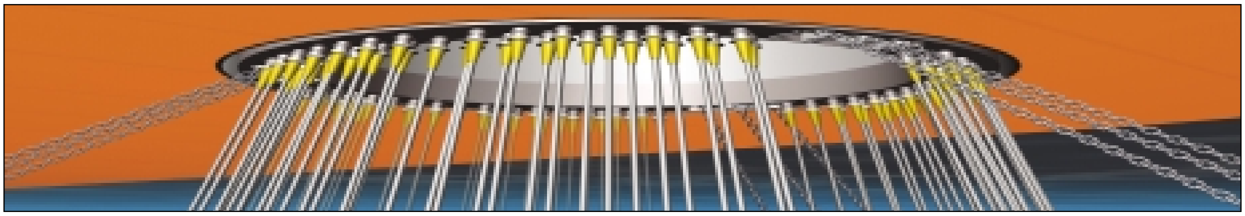


Deeper waters, larger fields, more wells, bigger FPSOs. The growth trend in offshore developments and associated floating vessels has been a steady one in recent years, with some FPSOs now being sized to handle around 250,000b/d of production. But somewhere along the line in this trend, single point mooring systems, which use an inboard turret to moor the vessel and provide access for risers while giving the FPSO the advantages of weathervaning, seem to have become tagged with a perception that they have already reached their upper size limit.

Witness the fact that the turret-moored FPSO with the largest number of risers currently in operation is in the Marlim South field offshore Brazil, where the *P35* FPSO carries 47 risers and is capable of handling up to 100,000b/d. Then take a look at the plethora of new FPSOs in operation or lined up for Brazil and West Africa, some of them with capacity for over 100 risers. For these vessels, spread mooring appears to be the favoured option, where the risers are brought onto the vessel through a long set of outboard porches – for example, the Barracuda *P43* FPSO for Brazil will have 104 riser slots on its port side (*OE* December 2001).

As all risers on a turret-moored FPSO must pass through the inside of the turret bearing, the bearing opening has been viewed as the governing factor on the number of risers that can fit within the turret, and that limit also controls the production rate that can be achieved from the field.

'If you look at existing systems in operation, a perception seems to have built up that turret-moored FPSOs can't handle more than about 50 risers,' says Chuck Garnero, project engineering manager with FMC Sofec in Houston. 'This is due to a combination of factors, including riser congestion, the deck space available, the size of the turret bearing and its load carrying capability. So projects where 50-100 risers have been called for have tended to opt in the main for spread moored FPSOs. One alternative is to manifold the wells subsea to reduce the number of risers, but this creates complex subsea piping, reduces operational flexibility, and larger, costly risers are needed.'

While spread mooring of FPSOs is well established, it does lose a key advantage offered by turret-moored vessels – the ability to weathervane. The geostationary turret, moored to the seabed by chains and anchors, enables the vessel to weathervane passively around it, naturally taking up a position pointing into the prevailing weather. This lowers environmental loads on the mooring system, enabling fewer and smaller chains and anchors to be used. But perhaps most critically, offloading operations can be carried out with shuttle tankers in tandem to the FPSO, which says Garnero, provides greater operational up-time and less risk of tanker collision compared with spread-moored FPSOs.

'Spread-moored vessels can require tugs to assist shuttle tankers, or dynamically positioned shuttle tankers to counteract the weather during offloading. Or they may use remote offloading systems employing a large buoy connected to the FPSO by mid-water flowlines, typical of those in West Africa. But this significantly increases the field development cost, and the accuracy in predicting fatigue life of the flowlines and buoy mooring lines is an issue currently under debate in the industry.'

Given this backdrop, FMC Sofec has developed a design for a very large turret (VLT) that would retain the benefits of weathervaning and double the riser handling capacity of current turret-moored vessels. Over 100 risers could pass through the moonpool, says the company, making a VLT FPSO suitable for large field developments in waters up to 3000m deep.

The key to the VLT breakthrough lies in the size and type of bearing which supports the turret inside the structure of the FPSO, and the manner in which it interfaces with the ship's structure at the deck level.

In conventional turret designs, the vertical bearing at deck level takes the weight of the turret, mooring system and risers, supporting loads measured in thousands of tonnes. For most turrets, this bearing typically incorporates a costly three-row roller bearing, consisting of many parts held between bearing races. Fabrication and assembly of such bearings is a precision engineering task as very tight tolerances must be achieved between the rollers and the flat bearing mounting surface to prevent the turret binding during rotation. This effect is further exaggerated as the FPSO 'hogs and sags' with the prevailing sea state, requiring that the bearing mounting be very rigid to resist flexing caused by the movement of the vessel hull and surrounding deck. The bearing mounting itself is installed on supports with spring-like characteristics to help isolate the bearing from the movement of the vessel.

'Achieving these machining tolerances – of the order of one third of a millimetre – across a large mechanical structure is not easy,' Garnero points out. 'In practical terms this has imposed limits in the size of bearings – and therefore the turrets.'

The largest three-row turret bearing installed to date as a single assembled unit measures around 8m in diameter. Beyond this, bearings must be fabricated in segments, adding to the challenge of achieving tight mechanical tolerance – 14m diameter is the industry limit so far.

FMC Sofec's answer to this is to use a different type of bearing for the VLT, simpler to build, more robust by nature, and capable of being scaled up to around 40m in diameter, limited only by the beam width of the vessel.

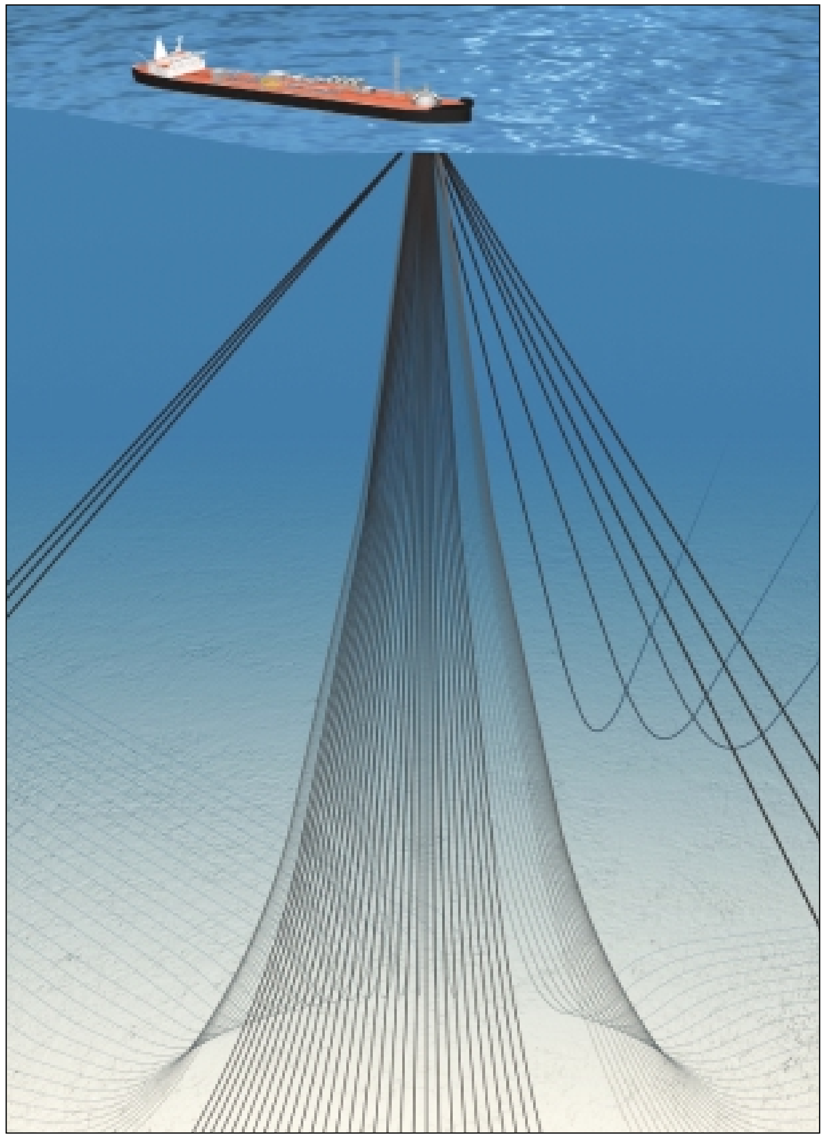
The technology for this is by no means new, and is already used in the offshore industry. The bearing is an AmClyde-type wheel and rail bearing like those used on heavy lift crane bases – dozens of these have been in operation for many years, and range up to some 28m in diameter on the massive cranes onboard Heerema's *Thialf* and Saipem's *S7000* construction vessels. These bearings consist of concentric rows of roller wheels which travel on rails – for a turret vertical bearing, the wheels would ride between two sets of rails, one set mounted at the top of the vessel moonpool, the other set on the underside of the turret's main deck (*see figure page 4*). Spring-loaded radial bearing wheels, to react to the horizontal loads in the plane of the vessel deck, would also be distributed around the circumference of the turret.

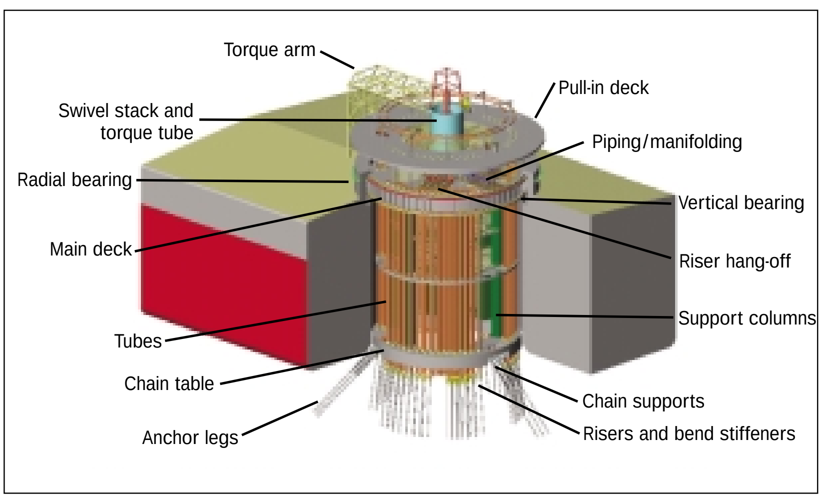
'This is a much simpler arrangement than roller bearings,' explains Garnero. 'They are similar to train wheels in compression with the loads at top and bottom. Container rings guide the wheels, which are typically 300mm to 600mm in diameter, to follow a circular path. The tolerances on fabricating the turret structure supporting these bearings are less demanding than for roller bearings, about 1mm, and they are easier to inspect, maintain or even replace *in situ*. And most importantly, the bearing can be assembled into a large diameter, opening up the turret diameter for more risers.'

Detailed design studies carried out by FMC Sofec indicate a VLT bearing diameter of 23m would accommodate 60 risers, 32m for 90 risers, and 41m for 120 risers. The risers would be spaced around the inner circumference of the turret in

LEFT: Risers passing through the chain table in the VLT design.

RIGHT: Turret-moored FPSOs could handle over 100 risers based on FMC Sofec's VLT design (below).





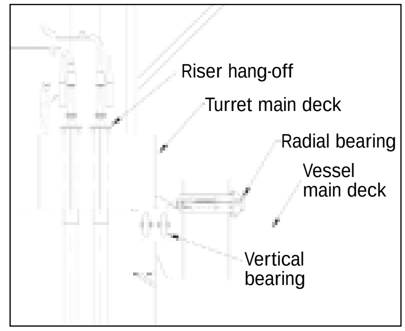
two circular rows – additional rows would induce 'shadowing' of risers, creating the potential for risers to hit one another as they are pulled in or out of the turret. As most of the load on the bearing comes from the risers, having these at the perimeter near the wheels reduces bending moments in the turret deck structure.

The VLT also demands less concentricity between turret and moonpool, which means the lower bearing at the chain table can have more tolerance. This removes a critical design condition required for conventional turrets for preventing 'pinching' at the chain table during hogging conditions.

But the VLT design is not only about robust wheels in the bearings. The deck of the turret is constructed as a hub-and-spoke shaped pancake structure which provides a degree of flexibility to accommodate the movement of the FPSO. For a 90-riser VLT, the turret deck would be 32m in diameter and 2.5m thick, with a weight of approximately 690t. The thickness-to-diameter ratio of this deck makes it strong enough to support the loads and yet compliant enough to flex when the FPSO is under extreme sagging and hogging conditions. Finite element analysis has shown that the most onerous condition is when the FPSO sags in a 100-year storm, causing the maximum vertical deflection of the vessel's deck at the turret location. This 'flexible' turret deck design is in contrast to the rigidity of conventional turret designs and has the effect of allowing the VLT deck to travel 'in concert' with the FPSO deck. Although these vertical deflections are relatively small – around 15mm for a 90-riser turret – the compliant turret deck ensures proper operation of the turret bearing.

Overall, the turret is a space frame structure, with the deck connected to the chain table at the vessel's keel level by six support columns – for the 90-riser turret, the chain table would weigh around 490t, with the 28m long, 2m diameter support columns totalling some 200t. Flexible risers would pass through protective I-tubes, hanging from the turret's deck.

'FE analysis has been carried out for a range of dynamic and static loading conditions,' says Garnero. 'We have confirmed that the maximum loads which the VLT would experience are well within the bearing's capacity. For example, the standard wheel and rail bearing design could take almost twice the loads experienced by a 120-riser VLT in 1300m of water. The bearing capacity could be increased further through heat treatment



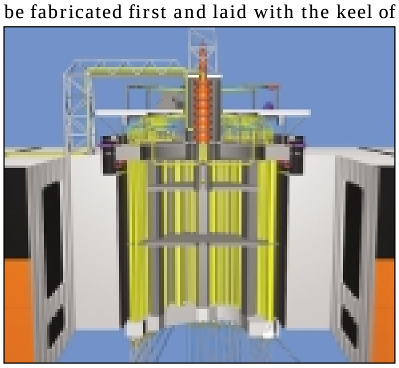
AmClyde-type wheel and rail bearings (above) can be assembled into large-diameter bearings (top right).

and wider wheels and rails, so we are confident the bearing would not be a limitation for water depths up to 3000m.'

While the VLT would be larger than any conventional turret, the company says its design is more efficient in terms of the use of turret steel required to carry the riser payload. Preliminary design of the VLT results in weights of 34t per riser for the 60 riser case, reducing to 31t per riser for 120 risers. These figures compare very favourably with existing turret designs – and those in shallower waters with shorter risers too. For example, for the Albacora *P31* FPSO turret offshore Brazil, having 28 risers in 330m of water, the ratio is 60t per riser, while the Barracuda *P-34* vessel rates at 56t per riser for its 34-riser system in 840m of water.

In addition to lighter construction, less demanding fabrication tolerances and a flexible pancake design, the VLT is said to offer other construction advantages. One of these is that all turret components can be installed from above.

'Conventional turrets are sometimes shaped like a truncated cone, having a larger diameter chain table to allow risers to flare out from the base,' says Garnero. 'In this case a lower turret assembly must be fabricated first and laid with the keel of the vessel for a newbuild, as it cannot be installed later from the top. As the VLT is a large diameter, it does not need to be flared at the base, but can be cylindrical. This means all components and equipment can be put in from above, which takes the turret off the critical construction path.'



VLT cross-section showing turret structure and deck layout.

The larger diameter of the VLT also means that other equipment associated with turrets – notably the swivel stack for transferring fluids across the moving interface between turret and vessel, winches for riser and mooring pull-ins, and pipework manifolding – can all be located on the turret main deck level. On smaller turrets, this equipment is normally installed on multiple decks added above, making the turret higher. Torque arms, which connect the outer swivel paths to the vessels, are usually located above all the piping manifolding on conventional turrets. By installing FMC Sofec's patented torque tube – a 6m diameter shell sitting around the swivel stack, originally developed for the Terra Nova project offshore Canada – only one large torque arm is required and this can be lower down as there is no need to avoid raised pipework manifolds on elevated decks. The overall effect is a lower overall turret arrangement plus a simpler access structure surrounding the turret mounted on the vessel's deck (*see diagram left*).

The diameter of the VLT is limited only by the physical dimensions of the FPSO. Hull strengthening around the moonpool is necessary for all turret-moored vessels – the degree of strengthening is determined by the portion of the vessel's beam occupied by the moonpool. Very large and ultra large crude carriers (VLCCs and ULCCs) are the typical sizes of vessels either converted to FPSOs, or equivalent to the scale of newbuild vessels. Beam dimensions for VLCCs range from 50-60m while ULCC beams are 60-70m. According to FMC Sofec, these dimensions are sufficient to accommodate the VLT designs, and a number of tankers with these dimensions exist in the marketplace.

And as the VLT seems to be ready to dispel misgivings about the feasibility of making turrets work for large deepwater fields, one other misconception Garnero points to is the belief that spread mooring with long riser porches provides greater riser spacing at the seabed and therefore less congestion and risk of risers touching. But with a conventional 3x3 (three groups of three anchor legs) turret mooring pattern, this is not true, he asserts.

'Once you get into over 500m of water depth, turret moorings actually give more riser touchdown spacing along the seabed. For example, for an FPSO in 1300m of water with 90 catenary risers with a departure angle of 7°, the VLT provides over twice the available touchdown length than spread mooring with riser porches on both sides of the FPSO. As the water depth increases, so does the riser touchdown area – in 3000m of water, this becomes three times the space available with spread mooring. In short, the 3x3 anchor leg configuration of a turret mooring provides more open area between anchor leg patterns, thus accommodating more riser approaches to the FPSO.'

Deeper waters, larger fields, more wells, bigger FPSOs. And perhaps soon, larger turrets. OE

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